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(54) Polarized illuminating device

Polarisierendes Beleuchtungsgerät

Dispositif d'illumination polarisé

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- **PATENT ABSTRACTS OF JAPAN vol. 10, no. 268 (E-436), 12 September 1986 & JP-A-61 090 584**
- **OPTIK vol. 13, no. 4, 1956, pages 158-168; H. SCHROEDER: "Optische Eigenschaften der Lichtteilung durch Interferenzpolarisatoren"**
- **APPLIED OPTICS vol. 19, no. 12, June 1980, pages 2046,2047, New York, US; A.M. TITLE et al.: "Improvements in birefringent filters"**

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a polarized illuminating device according to the preamble of claim 1, and to an image display apparatus as well as a projector using the same.

Related Background Art

Fig. 1 is a schematic view showing the principal structure of an example of a conventional image display apparatus.

This display apparatus is provided with a light source 1 composed for example of a halogen lamp or a metal halide lamp; a mirror 2 reflecting a part of the light emitted from the light source 1; a heat ray cut-off filter 3 for absorbing or reflecting the heat ray in the light entering directly from the light source 1 or indirectly from the mirror 2; a condenser lens 4 for converting the light, after removal of the heat ray, into a parallel beam; a polarizer 5 for converting the parallel light beam into linearly polarized light; a liquid crystal light valve 7 for modulating the linearly polarized light according to an image signal; a polarizer 8 for transmitting only a component of the modulated linearly polarized light parallel to the transmission axis thereof; and a projection lens 10 for projecting the linearly polarized light transmitted by the polarizer 8, in a magnified scale onto an unrepresented screen.

Fig. 2 is a schematic view showing the principal part of another example of such conventional projection display apparatus.

This apparatus is equipped with two polarizing beam splitters 6, 9 respectively in front of and behind the liquid crystal light valve 7, in place of the two polarizers 5, 8 in the apparatus shown in Fig. 1.

The projection display apparatus shown in Figs. 1 and 2 are associated with a drawback that the efficiency of utilization of light does not exceed 50 %, since, within the light emitted by the light source 1, a linearly polarized component transmitted by the polarizing beam splitter 6 alone is utilized for illuminating the liquid crystal light valve 7 while the perpendicularly polarized component is lost.

Fig. 3 shows a projection display apparatus disclosed in the JP-A-61-90584 for rectifying said drawback.

In this projection display apparatus the parallel light beam emerging from the condenser lens 4 enters a polarizing beam splitter 11, and the P-polarized component L_p is transmitted by the functional plane (an evaporated film formed on a diagonal plane between two rectangular prisms) 11a of the polarizing beam splitter 11, while the S-polarized component L_s is perpendicularly reflected to enter a total reflection prism 12. Being perpendicularly reflected again in the prism 12, the S-polarized component L_s emerges from the prism 12 in a direction same as that of the P-polarized component L_p. The S-polarized component L_s is polarized in a direction parallel to the functional plane 11a of the polarizing beam splitter 11, and the P-polarized component L_p is polarized in a direction perpendicular to that of the S-polarized component.

At the exit side of the total reflection prism 12 there is provided a $\lambda/2$-phase shifting plate 13, whereby said S-polarized component L_2 is subjected to a rotation of the polarizing direction by 90° and is converted into a P-polarized component L_p^*. Also at the exit side of the polarizing beam splitter 11 and the $\lambda/2$-phase shifting plate 13 there are respectively provided wedge-shaped lenses 14, 15 for light path deflection, whereby the P-polarized component L_p transmitted by the polarizing beam splitter 11 and the P-polarized component L_p^* converted by the $\lambda/2$-phase shifting plate 13 are subjected to light path deflection and mutually cross at a point P_0 on the entrance face of the liquid crystal light valve 7, thereby providing a synthesized light.

Consequently such projection display apparatus can illuminate the liquid crystal light valve 7 with both the S-polarized component L_s and the P-polarized component L_p separated by the polarizing beam splitter 11 and can therefore double the efficiency of light utilization in comparison with the apparatus shown in Fig. 2.

However, in the projection display apparatus disclosed in the above-mentioned JP-A-61-90584, since the P-polarized component L_p and the P-polarized component L_p^* converted by the $\lambda/2$-phase shifting plate 13 respectively enter the liquid crystal light valve 7 with an angle θ as shown in Fig. 3, it is necessary to select a considerably large distance from the wedge-shaped lenses 14, 15 to the liquid crystal light valve 7 in order to reduce this incident angle θ if the light valve 7 shows significant deterioration of characteristics depending on the incident angle.

For avoiding such drawback, there is conceived a parallel illuminating method in which the wedge-shaped lenses 14, 15 shown in Fig. 3 are removed, whereby the P-polarized component L_p and the converted P-polarized component L_p^* enter the liquid crystal light valve 7 in mutually parallel state. However, such parallel illumination method, if applied to the projection display apparatus disclosed in the JP-A-61-90584 cannot provide the expected result because the P-polarized component L_p and the converted P-polarized component L_p^* are not complete unless the light source 1 is a complete point or linear source providing completely parallel beams from the condenser lens 4. This will be explained further with reference to Fig. 4.

In case the light from a light source 1 with a finite diameter ϕ is condensed by a condenser lens 4 at a distance ℓ, the light emerging therefrom is not completely parallel but is spread within an angular range 2ω

($\omega=\tan^{-1}((\phi/2)/\ell)$). A ray α contained in the thus obtained non-parallel beam enters the $\lambda/2$-phase shifting plate 13 without the function of the polarizing beam splitter 11 and emerges from the phase shifting plate 13 with the P- and S-polarized components. Also a ray β is converted by the polarizing beam splitter 11 into the S-polarized component L_s, which is then reflected by the total reflection prism 12 and reflected again by the polarizing beam splitter 11. It thus emerges as a P-polarized component L_p^* from another position of the $\lambda/2$-phase shifting plate 13 as indicated by a ray β_1, or is lost by absorption or transmission at the surface of the phase shifting plate 13 as indicated by a ray β_2.

Further, the document OPTIK vol. 13, no. 4, 1956, pages 158-168; H. Schroeder: "Optische Eigenschaften der Lichtteilung durch Interferenzpolarisatoren" forming the preamble of claim 1 discloses a polarized illuminating device having a polarizing beam splitter for splitting a beam emitted from a radiation source into a first (reflected) beam and a second (transmitted) beam of mutually orthogonal planes of polarization. This device further comprises an arrangement of a 1/4 wavelength plate and a mirror, for rotating the plane of polarization of the first beam to generate a third beam of a plane of polarization which is the same as that of the second beam, and is capable of directing the second and third beams in a predetermined direction.

SUMMARY OF THE INVENTION

In consideration of the foregoing, the object of the present invention is to provide an improved polarized illuminating device capable of reducing the loss in the amount of light, whilst being capable of suppressing uneveness in the intensity or spectral distribution of the illuminating light.

This object is solved by the features set forth in claim 1.

Advantageously developed embodiments of the invention are subject-matter of the claims 2 to 10.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing the structure of an example of the conventional projection display apparatus;

Fig. 2 is a schematic view showing the structure of another example of the conventional projection display apparatus;

Fig. 3 is a schematic view showing the structure of a projection display apparatus disclosed in the JP-A-61-90584 ;

Fig. 4 is a schematic view showing a drawback encountered when the parallel illumination method is employed in the projection display apparatus shown in Fig. 3;

Fig. 5 is a view of an embodiment of a polarized illuminating device not according to the present invention;

Fig. 6 is a schematic view showing the optical path in the polarized illuminating device shown in Fig. 5;

Fig. 7 is a view of a further embodiment of a polarized illuminating device not according to the present invention;

Fig. 8 is a view of a still further embodiment of a polarized illuminating device not according to the present invention;

Fig. 9 is a view of another embodiment of a polarized illuminating device not according to the present invention;

Fig. 10 is a partial view of an embodiment of an image display apparatus provided with the polarized illuminating device shown in Fig. 9;

Figs. 11A and 11B are respectively a lateral view and a plan view of an embodiment of an image display apparatus provided with the polarized illuminating device shown in Fig. 5;

Fig. 12 is a view of the basic structure of a first embodiment of the polarized illuminating device of the present invention;

Fig. 13 is a schematic view of the optical path of the polarized illuminating device shown in Fig. 12;

Figs. 14 to 17 are views showing the details of second to fifth embodiments of the polarized illuminating device of the present invention;

Figs. 18 and 19A to 19C are respectively a view and charts showing a sixth embodiment of the polarized illuminating device of the present invention;

Figs. 20, 21, 22, 23A and 23B are views showing still other embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now the present invention will be clarified in greater detail by embodiments thereof shown in the attached drawings.

Fig. 5 is a schematic view of an embodiment of a polarized illuminating device not according to the present invention, and Fig. 6 is a view showing the optical path thereof.

This polarized illuminating device is composed of a polarizing beam splitter 26 having a function plane (an evaporated film formed on a diagonal plane at which two rectangular prisms are mutually adhered) for transmitting the P-polarized component L_p of a parallel light beam emerging from a condenser lens 4 while rectangularly reflecting the S-polarized component L_s; a total reflection prism 29 provided with a total reflection plane 29a contacting at an end thereof rectangularly with an end of the functional plane 26a of the polarizing beam splitter 26 and serving to rectangularly reflect the transmitted P-polarized component L_p; a $\lambda/4$ phase shifting plate 27 contacting at an end thereof, at an angle of 45°, with an end of the functional plane 26a of the polarizing beam splitter and with an end of the total reflection plane

29a of the total reflection prism 29, and adapted to receive the reflected S-polarized component L_s; and a reflecting plate 28 having a reflecting plane, composed of an aluminum evaporated film or an optical multi-layered film, adhered to the $\lambda/4$ phase shifting plate 27.

In the polarized illuminating device, the parallel light beam emerging from the condenser lens 4 is split into the P-polarized component L_p and the S-polarized component L_s, by respective transmission and rectangular reflection by the functional plane 26a of the polarizing beam splitter 26. This reflected S-polarized component L_s enters the $\lambda/4$ phase shifting plate 27, is then reflected by the reflecting plane of the reflecting plate 28, and is again transmitted by the phase shifting plate 27, thereby subjected to a rotation of the plane of polarization by 90° and thereby converted into a P-polarized component L_p*, which is transmitted by the functional plane 26a and emerges from the polarizing beam splitter 26. On the other hand, the transmitted P-polarized component L_p is rectangularly reflected by the total reflection plane 29a of the total reflection prism 29, and emerges therefrom parallel to the converted P-polarized component L_p*.

In this polarized illuminating device, as indicated by rays α_1, α_2, α_3, all the light entering the polarizing beam splitter 26 is received by the functional plane 26a thereof, and is split into the P-polarized component L_p and the S-polarized component L_s. Also all the S-polarized components L_s enter the phase shifting plate 27, thus being subjected to the rotation of plane of polarization. On the other hand, the P-polarized component L_p scarcely enters the $\lambda/4$ phase shifting plate 27. Also with respect to an arbitrary ray, the P-polarized component L_p emerging from the total reflection prism 29 and the converted P-polarized component L_p* emerging from the polarizing beam splitter 26 are mutually symmetrical in the vertical direction. Consequently, even if the light beam entering the polarizing beam splitter 26 becomes unbalanced due, for example, to a positional shift of the light source 1, there will result no abrupt change in the illumination intensity at the junction point of the P-polarized component L_p and the converted P-polarized component L_p*. Also since the P-polarized component L_p and the converted P-polarized component L_p* have the same optical path length, there can be prevented an imbalance in the illumination intensity resulting from uncollimated light. This is rendered possible by a structure in which the functional plane 26a of the polarizing beam splitter 26, the $\lambda/4$ phase shifting plate 27 and the total reflection plane 29a of the total reflection prism 29 are maintained in mutual contact with predetermined angles, and is not achievable in the conventional structure employing the $\lambda/2$ phase shifting plate 13 shown in Fig. 3, because the functional plane of the polarizing beam splitter 11 is parallel to the total reflection plane of the prism 12.

Also in the present polarized illuminating device, at the entry into the polarizing beam splitter 26, a ray obliquely entering the $\lambda/4$ phase shifting plate 27, such as γ in Fig. 6, may be lost by transmission or reflection by the phase shifting plate 27, but such loss can be prevented by forming an optical multi-layered film on the junction plane between the polarizing beam splitter 26 and the $\lambda/4$ shifting plate 27) which reflects a ray of a large incident angle, such as γ, and transmits the normal ray with a small incident angle.

Also an incident ray entering the total reflection plane 29a of the prism 29 with an incident angle smaller than the total reflection angle, such as δ shown in Fig. 6, is partially lost in the P-polarized component L_p due to partial transmission, but such loss can also be prevented by forming a multi-layered reflecting film or a metal reflecting film on the total reflection plane 29a.

As explained in the foregoing, the polarized illuminating device can improve the efficiency of light utilization, as the P-polarized component L_p and the S-polarized component L_s split by the polarizing beam splitter 26 can both be utilized for illuminating the light valve (not shown). Besides, a remarkable improvement can be achieved in the balance of illumination intensity which has been a problem in the parallel illumination of the liquid crystal light valve (not shown) with the P-polarized component L_p and the converted P-polarized component L_p*, and there is also achieved a reduction in the distance between the polarized illuminating device and the light valve, which has been difficult to achieve in the illuminating system with the synthesized light shown in Fig. 3. Thus, compactization of the image display apparatus is enabled.

The total reflection prism 29 may be integrally formed with a rectangular prism, positioned next to the total reflection prism 29, of the polarizing beam splitter 26.

Fig. 7 illustrates a further embodiment of a polarized illuminating device not according to the present invention.

The present embodiment is different from that shown in Fig. 5 in that the P-polarized component L_p, transmitted by the functional plane 36a of a polarizing beam splitter 36 immediately emerges therefrom, while the S-polarized component L_s reflected by the functional plane 36a is converted into a P-polarized component L_p * by a $\lambda/4$ phase shifting plate 37 and a reflecting plate 38, is then rectangularly reflected by the total reflection plane 39a of a total reflection prism 39 and emerges therefrom in a parallel manner to the P-polarized component L_p.

In this polarized illuminating device, the direction of the emerging light can be made the same as that of the incident light, without addition of other optical components. The P-polarized component and the converted P-polarized component L_p * have mutually different optical path lengths, but can provide the same advantages as those in the apparatus shown in Fig. 1.

The total reflection prism 39 may be formed integrally with a rectangular prism, positioned next to the total reflection prism 39, of the polarizing beam splitter

36.

Fig. 8 illustrates a still further embodiment of a polarized illuminating device not according to the present invention.

In the present embodiment, the reflecting plate 28 in Fig. 5 is replaced by a rectangular prism 40, for reflecting the S-polarized component L_s, reflected by the functional plane 46a of a polarizing beam splitter 46, without formation of an unnecessary polarized component.

In the present embodiment, the S-polarized component L_s is laterally inverted with respect to the central axis thereof, then enters a λ/4 phase shifting plate 47 from the rectangular prism 40, and is converted into the P-polarized component L_p*. Consequently, the converted P-polarized component L_p* and the P-polarized component L_p emerging from a total reflection prism 49 lack the symmetry explained in the apparatus shown in Fig. 1, so that the illumination intensity distribution tends to become unbalanced when the light bean entering the polarizing beam splitter 46 is unbalanced. Also the P-polarized component L_p emerging from the total reflection prism 49 and the converted P-polarized component L_p* emerging from the polarizing beam splitter 46 have mutually different optical path lengths, so that the use of uncollimated light may pose a problem. However, the present embodiment provides other advantages same as those in the apparatus shown in Fig. 1.

The total reflection prism 49 may be formed integrally with a rectangular prism, positioned next to the total reflection prism 49, of the polarizing beam splitter 46.

Fig. 9 illustrates another embodiment of a polarized illuminating device not according to the present invention.

The polarized illuminating device of the present embodiment is composed of a polarizing beam splitter 56 having a first functional plane 56a (an evaporated film formed on one of two diagonal planes for jointing three rectangular prisms) for transmitting the P-polarized component L_p of incident light beam and perpendicularly reflecting the S-polarized component thereof, and a second functional plane 56b (an evaporated film formed on the other of the two diagonal planes) contacting at an end thereof rectangularly with the first functional plane 56a; a λ/4 phase shifting plate 57 contacting at an end thereof, with an angle of 45°, with the other end of the second functional plane and adhered to a face of the polarizing beam splitter 56 opposite to the entrance face thereof; and a reflecting plate 58 having a reflecting plane adhered to the λ/4 phase shifting plate 57.

Among a parallel incident beam from a condenser lens (not shown), the S-polarized component L_s is reflected by the first functional plane 56a of the polarizing beam splitter 56 and immediately emerges therefrom. The P-polarized component L_p is transmitted by the first and second functional planes 56a, 56b of the polarizing beam splitter 56 and enters the λ/4 phase shifting plate 57. This component is converted into the S-polarized component L_s* by a rotation of the plane of polarization by 90° in the phase shifting plate 57 and the reflecting plate 58, is then perpendicularly reflected by the second functional plane 56b of the polarizing beam splitter 56, and emerges therefrom in a direction same as that of the above-mentioned S-polarized component L_s.

The present embodiment is not suitable for uncollimated light because the S-polarized component L_s and the converted S-polarized component L_s* have mutually different optical path lengths, but provide other advantages same as those in the apparatus shown in Fig. 5. Also the apparatus of the present embodiment may be utilized as an analyzer in an image display apparatus utilizing a liquid crystal light valve (as will be explained later), because of the absence of the phase shifting plate 57 and the reflecting plate 58 at the side opposite to the entrance side.

In the following there will be explained an embodiment of the image display apparatus obtained by combining the polarized illuminating device with other optical components.

Fig. 10 is a schematic view showing the principal part of an embodiment of the image display apparatus utilizing the polarized illuminating device shown in Fig. 9.

As shown in Fig. 10, the image display apparatus is provided with a light source unit 100 comprising a light source 1, a reflection mirror 2, a heat ray cut-off filter 3 and a condenser lens 4; a polarized illuminating device 101 shown in Fig. 9; and a cross dichroic prism 102 adhered at a face thereof to the exit face of the polarized illuminating device 101 and bearing reflective liquid crystal light valves 65R, 65G, 65B for red, green and blue colors respectively on other three faces; and forms a projector together with a projection lens 10 positioned opposed to the exit face of the polarized illuminating device 101.

Among a white parallel light beam emerging from the light source unit 100, the S-polarized component L_s is perpendicularly reflected by a first functional plane 56a of a polarizing beam splitter 56 constituting the polarized illuminating device 101 (cf. Fig. 9), and enters the cross dichroic prism 102. Also the P-polarized component L_p is converted into an S-polarized component L_s* by the λ/4 phase shifting plate 57 and the reflecting plate 58 as explained before, is then perpendicularly reflected by the second functional plane 56b of the polarizing beam splitter 56 (cf. Fig. 9), and enters the cross dichroic prism 102. Thus, the white parallel light beam is directed to the cross dichroic prism 102 after conversion into a linearly polarized beam, consisting of the S-polarized components L_s, L_s*, in the polarized illuminating device 101.

The linearly polarized polarized beam split split by the cross dichroic prism 102 into red, green and blue light beams R, G, B, which are respectively projected toward the reflective liquid crystal light valves 65R, 65G,

65B for red, green and blue colors. The liquid crystals used in the light valves are of ECB (electrically controlled birefringence) type or 45° TN (twisted nematic) type, and have a property of rotating the plane of polarization of the incident light, depending on the voltage applied according to image signals. Consequently, the light incident to the reflective light crystal light valves 65R, 65G, 65B is linearly polarized light composed of S-polarized components, but the reflected light contains a P-polarized component according to the image signal in each pixel. The reflected light beams are synthesized in the cross dichroic prism 102 and return to the polarized illuminating device 101. In this device 101, a pair of functional planes of the polarizing beam splitter 56 (Fig. 9) function as an analyzer, whereby the P-polarized component L_{po} in the synthesized reflected light is transmitted and projected onto a screen (not shown) through the projection lens 10. A part of the S-polarized component L_{so} in the synthesized reflected light entering the first functional plane 56a of the polarizing beam splitter 56 is perpendicularly reflected by the functional plane 56a and returns to the light source unit 100. Also, another part of the S-polarized component L_{so} entering the second functional plane 56b of the polarizing beam splitter 56 is perpendicularly reflected by the functional plane, is then converted into a P-polarized component by the $\lambda/4$ phase shifting plate 57 and the reflecting plate 58, is then transmitted by the second and first functional planes 56b, 56a, and returns to the light source unit 100. Consequently, in the present polarized illuminating device, the polarizing beam splitter 56 functions as a complete analyzer.

The above-explained image display apparatus provides advantages of improving the efficiency of light utilization since the white parallel light beam from the light source unit 100 can be converted without loss into a linearly polarized beam by the polarized illuminating device 101, and of significantly reducing the rear-focus length of the projection lens in comparison with that in the conventional image display apparatus, because of separation and synthesis of beams of different colors by means of the cross dichroic prism 102, thereby expanding the design freedom of the projection lens 10 and compactizing the entire projector. There is also provided another advantage that the polarized illuminating device 101 can be utilized as an analyzer.

Figs. 11A and 11B are respectively a side view and a plan view of an embodiment of the image display apparatus utilizing the polarized illuminating device shown in Fig. 5.

This image display apparatus is provided with a light source unit 100; a polarized illuminating device 111 shown in Fig. 5; a mirror 77 for perpendicularly reflecting the light beam from the polarized illuminating device 111 downwards; a polarizing beam splitter 78 for perpendicularly reflecting the S-polarized component of the beam reflected by the mirror 77 toward the polarized illuminating device 111 while transmitting the P-polarized component; and a cross dichroic prism 102 adhered on a lateral face thereof to the exit face of the S-polarized component of the polarized beam splitter 78, and having reflective liquid crystal light valves 65R, 65G, 65B for red, green and blue colors on three other lateral faces; and forms a projector together with a projection lens 10 positioned opposite to the side of the cross dichroic prism 112 with respect to the polarized beam splitter 78.

A white parallel light beam emitted from the light source unit 100 enters the polarized illuminating device 111, and the P-polarized component of the white parallel beam and the converted P-polarized component obtained from the $\lambda/4$ phase shifting plate 27 and the reflecting plate 28 (both P-polarized components being hereinafter collectively called P-polarized beam) enter the mirror 77. The P-polarized beam is totally reflected by the mirror 77 and enters the polarizing beam splitter 78. As the plane of polarization of the P-polarized beam is a S-polarized plane to the functional plane of the polarizing beam splitter 78, this beam is reflected by the plane and enters the cross dichroic prism 102. In the prism, the P-polarized beam behaves in the same manner as in the cross dichroic prism shown in Fig. 10, and the reflected light beams, modulated by the reflective liquid crystal light valves 65R, 65G, 65B according to an image signal, enter the polarizing beam splitter 78 which functions as an analyzer, as in the polarized illuminating device 10 shown in Fig. 10. Thus, the components of the reflected light beams transmitted by the polarizing beam splitter 78 are projected through the projection lens 10 onto a screen (not shown) to form an image thereon.

As explained above, the image display apparatus of the present embodiment provides, as in the apparatus shown in Fig. 10, advantages of improvement in the efficiency of light utilization, expansion of design freedom of the projection lens 10, and compactization of the entire structure.

The present embodiment employs the polarized illuminating device shown in Fig. 5, but the apparatus shown in Fig. 7 or 8 may naturally be employed likewise.

Also the image display apparatus employing a transmission liquid crystal light valve as shown in Fig. 3 may be obtained by combining the polarized illuminating device shown in Fig. 5, 7, 8 or 9 with the wedge-shaped lenses 14, 15 shown in Fig. 3. Also in the image display apparatus shown in Fig. 1 or 2, the polarized illuminating device may be positioned between the condenser lens 4 and the polarizing plate 5, or between the condenser lens 4 and the polarizing beam splitter.

The polarized illuminating device explained in the foregoing has the advantage of improving the efficiency of light utilization, by emitting either of the P- and S-polarized components of the incident light beam separated by a polarizing beam splitter, and also the other component after rotation of the plane of polarization by 90° with a $\lambda/4$ phase shifting plate and a reflecting member. Consequently, it enables to obtain an image display appa-

ratus capable of brighter display.

The polarizing beam splitter is usually so designed that the reflected S-polarized light and the transmitted P-polarized light are best separated at an incident angle of 45° to the functional plane. A high transmittance for the P-polarized component is obtained by selecting the refractive index of the multi-layered film constituting the functional plane so as to satisfy Brewster's law (Angle), but a decrease in transmittance is inevitable for any ray entering with an incident angle not matching Brewster's law. Consequently, if a spreading light beam enters the functional plane, the reflected light contains the P-polarized component, and the light beam emerging from the optical phase shifting plate contains the S-polarized component, so that the intensity of the light beam emerging from the polarizing beam splitter inevitably diminishes.

Also the optical phase shifting plate is unable to provide a phase difference of $\lambda/2$ or $\lambda/4$ in the entire wavelength range because of its wavelength dependence (dispersion), so that the emerging light inevitably contains the S-polarized component.

Consequently, in the polarized illuminating device utilizing such polarizing beam splitter and optical phase shifting plate, a pair of light beams of the same direction of polarization emerging from the device may not be mutually equal in the intensity, giving rise to an uneven intensity distribution of the illuminating light. Besides, the light beams may be mutually different in spectral distribution, so that the color of illuminating light may vary depending on the position of illumination.

In the following there will be explained a polarized illuminating device capable of suppressing the uneveness in the intensity distribution or the spectral distribution of the illuminating light, and an image display apparatus utilizing such polarized illuminating device.

In a preferred embodiment of the present invention, an optical filter is employed for rectifying the uneveness in the intensity of the paired light beams. This optical filter is inserted in either or both of the light paths of the P- and S-polarized components, and serves to attenuate the intensity of the incident light.

The optical filter can be of various types, such as a reflective filter for reflecting the incident light with simultaneous attenuation of intensity, a transmissive filter for transmitting the incident light with simultaneous attenuation of intensity, or a filter for absorbing the incident light.

Also the paired light beams can be given substantially equal spectral distributions by suitably regulating the wavelength characteristics of the optical filter.

The optical filter to be employed in the present invention is for example composed of a multi-layered optical film or an ordinary color absorbing filter. In the former, desired characteristics can be obtained by regulating the material and thickness of the multi-layered optical film.

Also the aforementioned polarizing beam splitter can be suitably designed to rectify the uneveness in the intensity between the paired light beams. As the intensity ratio of the P- and S-polarized components can be varied by the adjustment on the optical thin film constituting the functional plane (light splitting plane) of the polarizing beam splitter, the uneveness in the intensity of the paired light beams, resulting from the dispersion of the phase shifting plate, may be rectified by such method.

Also the optical components, such as mirrors and prisms, for defining the optical paths of the P-and S-polarized components may be given a function of the above-mentioned optical filter, in order to rectify the uneveness in the intensity of the paired light beams. In order to give the function of an optical filter to a mirror, the mirror is composed of a reflective filter with a multi-layered optical thin film. Also, in order to give the function of an optical filter to a transparent component such as prism, a light absorbing material is mixed in the material for the component at the manufacture thereof.

In a preferred embodiment explained in the following, the polarized illuminating device provided with

> a polarizing beam splitter for splitting the incident light beam into a first P-polarized component and a first S-polarized component;
> a $\lambda/4$ phase shifting plate positioned in contact with an end of the functional plane of the polarizing beam splitter and adapted to receive the first P-polarized component and the first S-polarized component; and
> a reflective member for reflecting the first P-polarized component or the first S-polarized component transmitted by the $\lambda/4$ phase shifting plate toward the phase shifting plate, wherein the first P-polarized component or the first S-polarized component is converted respectively into a second S-polarized component or a second P-polarized component by the $\lambda/4$ phase shifting plate and the reflective member, and the first and second P-polarized components or the first and second S-polarized components are emitted from the device,
> comprises at least a single optical filter positioned in contact with an end of the functional plane of the polarizing beam splitter and adapted to effect transmission, reflection or absorption on either one of two different polarized components, in the course from the separation of the first P-polarized component and the first S-polarized component by the polarizing beam splitter to the emission of the first and second P-polarized components or the first and second S-polarized components.

In another preferred embodiment to be explained later, the polarized illuminating device provided with

> a polarizing beam splitter with a functional plane for transmitting the P-polarized component of the inci-

dent light beam and perpendicularly reflecting the S-polarized component thereof;

a reflective member positioned in contact at an end thereof perpendicularly to an end of the functional plane of the polarizing beam splitter and perpendicularly reflecting the transmitted P-polarized component;

a λ/4 phase shifting plate positioned in contact at an end thereof, with an angle of 45°, with an end of the functional plane of the polarizing beam splitter and being in contact with an end of the reflecting surface of the reflective member, and receiving the reflected S-polarized component; and

a reflective plate with a reflective plane position close to the λ/4 phase shifting plate, wherein the reflected S-polarized component is converted into a P-polarized component by the λ/4 phase shifting plate and the reflective plate, and wherein the converted P-polarized component and the transmitted P-polarized component are emitted from the device,

comprises at least an optical filter in contact with an end where the functional plane of the polarizing beam splitter and the λ/4 phase shifting plate are in mutual contact, wherein the optical filter includes

at least one of a first optical filter which either serves also as the reflective member or is positioned in contact therewith or is positioned in the vicinity thereof,

a second optical filter positioned at the entrance side of the λ/4 phase shifting plate, and

a third optical filter which either serves as the reflective member positioned close to the λ/4 phase shifting plate or is positioned in contact with the reflective member or is positioned in the vicinity thereof, and transmits, reflects or absorbs a part of the incident light beam.

In these two preferred embodiments, either one of the P- and S-polarized components split by the polarizing beam splitter is introduced into the λ/4 phase shifting plate and the reflective member to rotate the plane of polarization by 90° to coincide with that of the other component, whereby the incident light beam can be fully utilized by the emission of both polarized components.

As the functional plane of the polarizing beam splitter and the λ/4 phase shifting plate are positioned in mutual contact at an end, no ray can enter the λ/4 phase shifting plate without passing the functional plane of the polarizing beam splitter or can re-enter the functional plane without passing the λ/4 phase shifting plate.

The S-polarized component reflected by the functional plane of the polarizing beam splitter contains a considerable amount of P-polarized component resulting from non-perpendicularly incident rays, and the converted P-polarized component obtained by the λ/4 phase shifting plate and the reflective member also contains a considerable amount of S-polarized component because the λ/4 phase shifting plate cannot provide a phase difference of λ/4 over the entire wavelength range, but the reflectance for the S-polarized component of the polarizing beam splitter can be made close to 100 % for both perpendicularly and non-perpendicularly incident rays.

Also the two emitted P-polarized components may mutually differ in intensity or in color, based on the characteristics of the polarizing beam splitter, particularly the incident angle is dependent on the transmittance of the P-polarized component, the spectral dispersion of the λ/4 phase shifting plate, the reflection loss of the reflective plane contacting the phase shifting plate, the reflection loss of the reflective plane for perpendicularly reflecting the P-polarized component transmitted by the polarizing beam splitter etc. However, the optical filter positioned in contact with an end of the functional plane of the polarizing beam splitter enables correction of intensity and/or color independently of the two emitted P-polarized components without generating light leakage, so that no overall unevenness nor local variation in the central area in the illumination intensity or color is encountered even in the parallel illumination system.

Fig. 12 is a view of a first embodiment of the polarized illuminating device of the present invention, and Fig. 13 is a schematic view showing the optical path thereof.

This polarized illuminating device 121 is provided with a polarizing beam splitter 26 having a functional plane (an evaporated film formed on a diagonal plane where two rectangular prisms are adhered) for transmitting the P-polarized component L_p of a parallel beam emerging from a condenser lens 4 while perpendicularly reflecting the S-polarized component L_s thereof; a prism 30 positioned in contact at an end thereof perpendicularly with an end of the functional plane (light splitting plane) 26 of the polarizing beam splitter, and having a reflective plane 30a which is provided with an optical filter and reflects the transmitted P-polarized component L_p perpendicularly; a λ/4 phase shifting plate 27 positioned in contact at an end thereof, with an angle of 45°, with an end of the functional plane 26a of the polarizing beam splitter 26, being in contact with an end of the reflective plane 30a of the prism 30, and receiving the reflected S-polarized component L_s; and a reflective plate 28 having a reflective plane adhered to the λ/4 phase shifting plate 27.

The polarizing beam splitter 26 is selected so as to be capable of splitting the polarized components over the entire visible wavelength range, particularly with a high reflectance for the S-polarized component, and the λ/4 phase shifting plate 27 is composed of an optical crystal capable of providing a phase difference of λ/4 at the approximate center of the wavelength range to be used.

The reflective plate 28 is provided with a reflective plane composed of an aluminum evaporated film. The reflective plane 30a is provided, as will be explained lat-

er, in succession from the side of beam splitter 26, with an aluminum evaporated film and an absorbing filter showing a weak absorption of a part, particularly red and blue regions, of the incident light.

In the present polarized illuminating device 121, the parallel beam emerging from the condenser lens 4 is split into the P-polarized component L_p and the S-polarized component L_s by transmission and perpendicular reflection, respectively, by the functional plane 26a of the polarizing beam splitter 26. The reflected S-polarized component enters the $\lambda/4$ phase shifting plate 27, is then reflected by the reflective plane of the reflective plate 28, and is again transmitted by the phase shifting plate 27, thereby being subjected to a rotation of the plane of polarization by 90° and, thus, converted into a P-polarized component L_p^* which is transmitted by the functional plane 26a and emerges from the polarizing beam splitter. On the other hand, the transmitted P-polarized component L_p is perpendicularly reflected by the reflective plane 30a of the prism 30 and emerges therefrom in parallel to the converted P-polarized component L_p^* but along a different light path.

Also in the present polarized illuminating device 121, all the light beams entering the polarizing beam splitter 26 are received received by the functional plane 26a thereof, as indicated by rays α_1, α_2, and α_3 in Fig. 13, and split into the P-polarized components L_p and the S-polarized components L_s. Also the S-polarized components L_s are all received by the $\lambda/4$ phase shifting plate 27 and are subjected to the rotation of plane of polarization. Inversely, the P-polarized components never enter the phase shifting plate 27. Also with respect to any arbitrary ray, the P-polarized component L_p emitted from the prism 30 and the converted P-polarized component L_p^* emitted from the polarizing beam splitter 26 are mutually symmetrical in the vertical direction. Consequently, an abrupt change in the illumination intensity can be prevented at the connection of the P-polarized component L_p and the converted P-polarized component L_p^* even if the incident light beam to the polarizing beam splitter becomes unbalanced by, for example, a positional deviation of the light source 1.

Rays emerging from the condenser lens 4 which are not parallel to the optical axis, such as α_1 and α_3 shown in Fig. 13, enter the polarizing beam splitter 26 non-perpendicularly, so that the incident angle to the functional plane 26a is also deviated from 45°. Consequently, the S-polarized component reflected by the functional plane 26a of the polarizing beam splitter 26 contains the P-polarized component of such non-parallel rays. Also the light converted by the $\lambda/4$ phase shifting plate 27 and the reflective plate 28 contains the S-polarized component because the phase difference provided by the phase shifting plate 27 is associated with a dispersion depending on the wavelength. However, as the reflectance of the polarizing beam splitter 26 for the S-polarized component can be made high for both the parallel and non-parallel incident rays, the structure of the present embodiment can provide a sufficiently high depolarization ratio in the emitted P-polarized light L_p^*.

In the course of the reflection of the S-polarized component L_s by the polarizing beam splitter 26, and the conversion thereof in the $\lambda/4$ phase shifting plate 27 and the reflective plate 28 into the P-polarized components L_p^* as shown in Fig. 12, the intensity of the P-polarized component L_p^* is reduced to T·R times of that of the S-polarized components L_s, wherein T is the rotation of the plane of polarization in two passings (going and returning) through the phase shifting plate 27 while R is the reflectance of the reflective plate 28, so that the emitted P-polarized components L_p, L_p^* become mutually different in intensity and in color. The reflective plane 30a may be given an attenuating effect for preventing such differences. Examples of the structure of such reflective plane are shown in Figs. 14 to 18, wherein same components as those in Fig. 12 are represented by same numbers.

In Fig. 14, there are shown a reflective plane 29c composed of an aluminum evaporated film formed on the surface of the prism 30, and a light absorbing filter 29b. The P-polarized component L_p transmitted by the polarizing beam splitter 26 is partially absorbed by the filter 29b, then perpendicularly reflected by the reflective plane 29c, again partially absorbed by the filter 29c and emitted as the P-polarized component L_p' of predetermined intensity and spectral distribution. The absorbance of the absorbing filter 29b for different wavelength components has to be adjusted such that both P-polarized components L_p' and L_p^* become mutually equal in intensity and in color (spectral distribution).

In Fig. 15, half-reflecting planes (half mirrors) 29d, 29e composed for example of multi-layered optical films are formed stepwise on the diagonal faces of the prism 30. The P-polarized component L_P transmitted by the polarizing beam splitter 26 is partially reflected by the half-reflecting planes 29d, but the remaining portion is transmitted. This portion is perpendicularly reflected by a reflective plane 29c composed of an aluminum evaporated film and reaches the half-reflecting planes 29e. The portion reflected by the half-reflecting planes 29d is transmitted by the polarizing beam splitter 26 as a P-polarized component L_p''. On the other hand, the P-polarized component reaching the half-reflecting planes 29e is partially reflected, and the reflected portion returns to the half-reflecting planes 29d by way of the reflective plane 29c, while the remaining portion is transmitted by the half-reflecting planes 29c and is emitted as a P-polarized component L_P'. The light reflected by the half-reflecting planes 29e and returning to the half-reflecting planes 29d is partially transmitted as the P-polarized component L_p'', and the remaining portion is again reflected and propagates towards the reflective plane 29c. The above-explained procedure is repeated whereby the P-polarized component is divided into L_p' and L_p''. Thus, the reflectance and transmittance of the half-reflecting planes 29d, 29e are to be selected such

that the P-polarized components L_p' and L_p^* become mutually equal in intensity and color. Also in case only either of the half-reflecting planes 29d and 29e is employed, similar advantages can be expected by suitably selecting the reflectance and transmitance thereof. An area 29f, surrounded by the reflecting planes 29c, 29d and 29e, may also be filled (constituted) with glass of a predetermined reflective index, whereby it is rendered possible to utilize the total reflection at the interface with air and, thus, to dispense with the reflective plane 29c composed of aluminum evaporated film.

In Fig. 16, there are provided a multi-layered film 29g, and an absorbing film 29b for absorbing the light transmitted by the film 29g. The mutual optically adhesion of both films allows to regulate the structure of the film 29g thereby controlling the reflectance thereof to the P-polarized component L_p in such a manner that the P-polarized component L_p' becomes equal to the P-polarized component L_p^*.

In Fig. 17, there are provided an optical filter 29i which is an optical multi-layered film 29i formed on a reflective plane of the prism 30, and a prism 29j optically adhered to the film 29i. The film 29i is so designed that the P-polarized components L_p' and L_p^* become mutually substantially equal in intensity and in color.

In the polarized illuminating device 121 of the structures shown in Figs. 12 to 17, the incident light to the polarizing beam splitter 26, if obliquely entering the λ/4 phase shifting plate 27 as exemplified by a ray γ in Fig. 13, may result in a loss in the intensity by transmission or absorption by the phase shifting plate 27. However, such light loss can be prevented by forming, on the junction plane of the polarizing beam splitter 26 and the λ/4 phase shifting plate 27, an optical multi-layered film which reflects a ray of a large incident angle, such as the ray γ, but transmits the normal ray of a smaller incident angle.

As explained in the foregoing, the present polarized illuminating device 121 can improve the efficiency of light utilization, since both the P-polarized component L_p and the S-polarized component L_s, split by the polarizing beam splitter, can be utilized for illuminating the liquid crystal light valve (not shown). It can also drastically reduce the imbalance of illumination intensity distribution which has been a problem in the parallel illumination system with the P-polarized component L_p and the converted P-polarized component L_p^*, and can achieve a reduction in the distance between the polarized illuminating device and the liquid valve, a target difficult to achieve in the conventional illuminating system with synthesized light as shown in Fig. 3, thereby enabling the compactization of the image display apparatus employing the polarized illuminating device 121 of the present invention.

The prism 30 may be formed integrally with a rectangular prism of the polarizing beam splitter, positioned adjacent to the prism 30.

In the above-explained embodiments, the optical filters are formed integrally on the prism 30, but such optical filter may naturally be formed separately. Also such optical filters may be provided in the optical path of the P-polarized component L_p after emerging from the prism 30 and/or in the optical path of the P-polarized component L_p^* after emerging from the beam splitter 26.

In the present invention there may also be employed, in addition to the filters capable of regulating both the light amount (intensity) and the color (spectral distribution) such as those shown in the foregoing embodiments, a filter for regulating the intensity only such as a neutral density (ND) filter. It is also possible to regulate the intensity with an ND filter and the color with a color filter, by positioning these filters in at least one of the optical paths for the P-polarized components L_p, L_p^*. Furthermore, a color absorbing material may be mixed in the prism 30 or prisms constituting the beam splitter 26 to provide these components with a filter function.

Fig. 18 shows still another embodiment of the present invention, wherein the structure other than the reflective plane 28 and 30a is the same as that shown in the foregoing embodiments in Figs. 12 to 17 and will therefore, not be explained.

The λ/4 phase shifting plate 27 is designed so as to provide a phase difference of λ/4 in the green wavelength range. Thus, the phase shifting plate 27 has a function, in the green wavelength range, of rotating the plane of polarization by approximately 90° in two passages of the light, but in the red and blue wavelength ranges of which the central wavelengths are different by about 100 nm from that of said green wavelength range, the percentage of conversion from an incident polarized component to the orthogonally polarized component diminishes to about 90 %. Consequently, if the reflective planes 28 and 30a have the same reflectance, the P-polarized component L_p^* reflected by the reflective plane 28 becomes weaker in intensity than the P-polarized component L_p' reflected by the reflective plane 30a by about 10 % in the red and blue wavelength ranges.

As will be explained in the following, in the present embodiment it is rendered possible to eliminate such imbalance in intensity and in color between the polarized components L_p^* and L_p'.

The reflective plane 28 is composed, in succession from the side of the beam splitter 26, of a multi-layered film 28b and an aluminum evaporated film 28a. Also, the reflective plane 30a is composed, from the side of the prism 30, of a multi-layered film 29k and an aluminum evaporated film 29c.

The reflectance of aluminum in the visible wavelength range is about 90 % at highest. On the other hand, the reflectance of the multi-layered films 28b, 29k can be considerably arbitrarily selected with a range from 0 to 100 %, depending on the layer structure. On the other hand, a stable reflectance can be easily obtained with aluminum, independently of the thickness thereof, butt the multi-layered film requires a precisely controlled film forming process for obtaining stable re-

flective characteristics, as the reflectance depends greatly on the film thickness.

In the present embodiment, each of the reflective planes 28, 30 is composed of a combination of a metal film, particularly an aluminum film, which can easily provide a stable reflectance despite of a certain reflection loss, and a multi-layered film which provides a larger freedom in the selection of reflectance, thereby enabling stable and delicate control of the difference of about 10 % in intensity and in color between the P-polarized components L_p' and L_p^* resulting from the dispersion characteristics specific to the λ/4 phase shifting plate, as will be explained in more detail in the following.

Figs. 19A, 19B and 19C, respectively, show the reflectance of an aluminum film, the reflectance of a multi-layered film, and the overall reflectance including the multiple reflections between both films, in the absence of mutual interference among the lights reflected by the films. A portion not reflected by the aluminum film is lost. The total reflectance R_{tot} is determined as follows:

$$R_{tot.} = \frac{R + r - 2HR}{1 - rR}$$

(= r + (1 - r)R(1 - r) + (1 - r)RHR(1 - r) + ...)
wherein

r : reflectance of optical multi-layered film
R : reflectance of aluminum.

As shown in Fig. 19C, the variation in the total reflectance R_{tot} is several times to several tens of times smaller than that in the reflectance of the multi-layered film, so that the total reflectance R_{tot} is affected little by a certain fluctuation in the reflectance of the multi-layered film.

Consequently, it is relatively easy to control the total reflectance with a precision of 1 % or less also by the control of the reflectance of the multi-layered films 28b, 29k.

In case the aluminum film and the multi-layered film are in mutual contact or are separated only by a distance of the order of wavelength, the multi-layered film has to be designed in consideration of the interference of the reflected lights from both films. However, there is still applied the same basic principle of controlling the reflectance, in excess of the reflectance of aluminum of 90 %, with the multi-layered film, so that the control of reflectance is easier in comparison with the control by the multi-layered film alone.

In the following there will be explained two combinations of the reflective planes 28, 30b shown in Fig. 18.

In the first combination, in the reflective plane 28, the multi-layered film 28b is designed so as to provide the aluminum film 28a with a reflection enhancing function with little wavelength dependence in the visible range, thereby minimizing the reflection loss of the reflective plane 28. On the other hand, in the reflective plane 30a, the multi-layered film 29k enhances the reflection of the aluminum film 29c strongly in the green wavelength region and weakly in the red and blue wavelength regions, thereby suppressing the imbalances in intensity and in color of the P-polarized components L_p' and L_p^* resulting from the influence of the phase shifting plate 27. This structure provides the highest efficiency of light utilization.

In the second combination, in the reflective plane 28, the optical multi-layered film 28b provides the aluminum film 28a with reflection enhancement, weakly in the green wavelength region and strongly in the red and blue wavelength regions, thereby cancelling the characteristics of the λ/4 phase shifting plate 27 and obtaining a P-polarized component L_p^* balanced in the intensity of red, green and blue colors. On the other hand, in the reflective plane 30a, the multi-layered film 29k provides the aluminum film 29c with a reflection enhancement with little wavelength dependence in the visible range in such a manner that the P-polarized components L_p' and L_p^* become balanced in intensity and in color.

Fig. 20 shows still another embodiment of the present invention, having an absorptive or reflective color filter 31, and a total reflection plane 30a of the prism 30. The incident light enters a prism 26 from the right-hand side, and is separated by the functional plane 26a into the P-polarized (transmitted) component L_p and the S-polarized (reflected) component L_s. The P-polarized component is reflected by the reflective plane 30a of the prism 30, constituting an interface with air, and emerges upwards. The S-polarized component is transmitted by the color filter 31, is then converted into a P-polarized component by the rotation of plane of polarization by 90° in the λ/4 phase shifting plate 27 and the reflective plate 28, is again transmitted by the color filter 31 in the opposite direction, is further transmitted by the functional plane 26a and emitted upwards. The color filter 31 has such spectral characteristics as to correct the spectral distribution of the polarized component returning to the functional plane 26a after being converted in the λ/4 phase shifting plate 27 and the reflective plate 28 to the spectral distribution of the P-polarized component L_p. Consequently/the P-polarized components L_p, L_p^* have a same spectral distribution, or a same color.

Fig. 21 shows still another embodiment of the present invention, in which a multi-layered reflective color filter 28 is provided in contact with the λ/4 phase shifting plate 27.

This embodiment effects correction of color (spectral distribution) when the S-polarized component coming from the plane 26a and through the phase shifting plate 27 is reflected by the reflective color filter 28. The spectral characteristics of the reflective color filter 28 is so selected that the spectral distributions of the P-polarized components L_p and L_p^* become mutually equal, so that both components have a same color.

Fig. 22 shows still another embodiment of the present invention.

The polarized illuminating device 121 of the present

embodiment is different from that shown in Fig. 12 in that the P-polarized component L_p transmitted by the functional plane 36a of the polarizing beam splitter 36 is immediately emitted therefrom, while the S-polarized component L_s reflected by the functional plane 36a is converted into the P-polarized component L_p^{**} by the λ/4 phase shifting plate 37 and the reflective plate 38, is then perpendicularly reflected by the total reflection plane 39a of the total reflection prism 39 and is emitted therefrom in parallel to the aforementioned P-polarized component L_p. The P-polarized components L_p, L_p^* are adjusted to a same color by adding an absorptive or reflective optical filter explained above to the reflective plate 38 or the reflective plane 39a.

The above-explained polarized illuminating device 121 can match the direction of emitted beams with that of incident beam without the addition of other optical components. The device of the present embodiment may be incompatible with the uncollimated light because the P-polarized component L_p and the converted P-polarized component L_p^* have different optical path lengths, but provide other advantages same as those in the device shown in Fig. 12.

The total reflection prism 39 may be formed integrally with a rectangular prism of the polarizing beam splitter 35 positioned adjacent to said total reflection prism.

In the embodiments shown in Figs. 20 to 22, the unbalance in the intensities of the P-polarized components L_p, L_p^* can be corrected by positioning an absorptive filter, such as an ND filter, in at least one of the optical paths of the components.

Also, instead of the use of such optical filter, the characteristics of the polarizing beam splitter may be suitably controlled to correct the intensity uneveness resulting from the dispersion by the phase shifting plate.

In the following there will be explained an embodiment of the image display apparatus, employing the polarized illuminating device of the present invention in combination with other optical components.

Figs. 23A and 23B are respectively a side view and a plan view, showing the principal part of this embodiment.

The image display apparatus is provided with a light source unit 110; a polarized illuminating device 121 shown in one of Figs. 12 to 21; a mirror 77 for reflecting the light beam from the device 121 perpendicularly downwards; a polarizing beam splitter 78 for perpendicularly reflecting the S-polarized component of the light beam reflected by the mirror 77 toward the polarized illuminating device 121 while transmitting the P-polarized component of the light beam; and a cross dichroic prism 112 adhered at a lateral face thereof to the emitting plane for the S-polarized component of the polarizing beam splitter 78, and bearing reflective liquid crystal light valves 75R, 75G, 75B for red, green and blue colors on other three lateral faces; and forms a projector together with a projection lens 113 positioned at a side of the polarizing beam splitter 78 opposite to the cross dichroic prism 112.

A parallel white light beam from the light source unit 100 enters the polarized illuminating device 121 which emits to the mirror 77, as shown in Figs. 12 to 21, the P-polarized component of the white light beam and the P-polarized component converted by the λ/4 phase shifting plate 27 and the reflective plate 28 of a same intensity (the P-polarized component and the converted P-polarized component being hereinafter collectively called P-polarized beams). The P-polarized beams are totally reflected by the mirror 77 and enter the polarizing beam splitter 78. As the P-polarized beams have an S-polarized plane with respect to the functional plane of the polarizing beam splitter 78, they are reflected by the functional plane and enter the cross dichroic prism 112. The P-polarized beams are modulated by the reflective liquid crystal light valves 75R, 75G, 75B, and the resulting beams enter the polarizing beam splitter 78 which functions as an analyzer, whereby the reflected components transmitted by the beam splitter 78 are projected onto a screen (not shown) through the projection lens 113, thereby forming an image on the screen.

In the foregoing embodiments, the correction has been directed to the uneveness in the intensity in a pair of illuminating light beams resulting from the dispersion in a phase shifting plate, but additional correction may be incorporated in order to correct the uneveness resulting from the dispersion in the polarizing beam splitter. Also, the phase shifting plate may be composed of an optical crystal, a film or a liquid crystal.

Claims

1. A polarized illuminating device (121) for converting a beam (Ls + Lp) emitted from a radiation source (1; 110) into a polarized beam (Lp, Lp*; Lp', Lp*), said device comprising a polarizing beam splitter (26; 36) for splitting said beam (Ls + Lp) emitted from said radiation source (1; 110) into a first beam (Ls) and a second beam (Lp; Lp') of mutually orthogonal planes of polarization, an arrangement of a 1/4 wavelength plate (27; 37) and a first mirror (28; 38), for rotating the plane of polarization of said first beam (Ls) to generate a third beam (Lp*) of a plane of polarization which is the same as that of said second beam (Lp; Lp'), and a second mirror (30a; 39a) which is arranged such that said second and third beams (Lp; Lp' / Lp*) are directed in a same predetermined direction, **characterized by** an optical filter (28b; 31) which is arranged such that said second and third beams (Lp; Lp' / Lp*) become mutually equal in intensity and/or color.

2. A device according to claim 1, wherein said polarizing beam splitter (26) is adapted to generate said first beam (Ls) by reflecting the S-polarized compo-

nent of said beam (Ls + Lp) of said radiation source (1), and to generate said second beam (Lp) by transmitting the P-polarized component of said beam (Ls + Lp) of said radiation source (1).

3. A device according to claim 1 or 2, wherein said first mirror (28) or said second mirror (30a) is provided with said optical filter (28b).

4. A device according to one of the preceding claims, wherein said optical filter (31) is provided between said polarizing beam splitter (26) and said arrangement comprising said 1/4 wavelength plate (27) and said first mirror (28).

5. An device according to one of the preceding claims, wherein said optical filter (28b; 31) has a multi-layered structure.

6. An image display apparatus comprising a radiation source (1), a generator (75) for generating an image by modulating a polarized beam (Lp, Lp*; Lp', Lp*), and a directing means for directing a beam (Ls + Lp) from said radiation source (1) to said generator (75), said directing means comprising said polarized illuminating device (121) according to one of the preceding claims.

7. An apparatus according to claim 6, wherein said directing means has a collimator (4) for converting said beam (Ls + Lp) from said radiation source (1) into a substantially parallel beam which is introduced into said polarized illuminating device (121).

8. A projector comprising an image display apparatus according to claim 6 or 7, and a projection optical system (113) for projecting the image generated by said generator (75) onto a predetermined plane.

9. A projector according to claim 8, further comprising a cross dichroic mirror (112) to which said second and third beams (Lp, Lp*) are directed, said generator (75) having

   a first light modulator (75G) for modulating and reflecting the polarized beam for a first color component (G) of said beams (Lp, Lp*) transmitted through said cross dichroic mirror (112) along a first direction, and for generating a beam indicative of a first image,
   a second light modulator (75B) for modulating and reflecting the polarized beam for a second color component (B) of said beams (Lp, Lp*) reflected in a second direction by said cross dichroic mirror (112), and for generating a beam indicative of a second image, and
   a third light modulator (75R) for modulating and reflecting the polarized beam for a third color component (R) of said beams (Lp, Lp*) reflected in a third direction by said cross dichroic mirror (112), and for generating a beam indicative of a third image,
   wherein said projection optical system (113) is capable of receiving said beams indicative of said first, second and third image, respectively, through said cross dichroic mirror (112) and said polarizing beam splitter (26) of said polarized illuminating device, and of projecting a color image with said beams.

10. A projector according to claim 9, wherein each of said light modulators (75G, 75B, 75R) is composed of a liquid crystal panel.

Patentansprüche

1. Polarisationsbeleuchtungsgerät (121) zur Umwandlung eines von einer Strahlungsquelle (1, 110) emittierten Strahls (Ls + Lp) in einen polarisierten Strahl (Lp, Lp*, Lp', Lp*), wobei das Gerät einen Polarisationsstrahlenteiler (26, 36) zur Teilung des von der Strahlungsquelle (1, 110) emittierten Strahls (Ls + Lp) in einen ersten Strahl (Ls) und einen zweiten Strahl (Lp, Lp') mit zueinander orthogonalen Polarisationsebenen, eine Anordnung aus einer 1/4-Wellenlängen-Platte (27, 37) und einem ersten Spiegel (28, 38) zur Drehung der Polarisationsebene des ersten Strahls (Ls), um einen dritten Strahl (Lp*) mit einer Polarisationsebene zu erzeugen, welche gleich der des zweiten Strahls (Lp, Lp') ist, und einen zweiten Spiegel (30a, 39a) aufweist, welcher derart angeordnet ist, daß der zweite und der dritte Strahl (Lp, Lp'/Lp*) in eine gleiche festgelegte Richtung gelenkt werden, **gekennzeichnet durch** ein optisches Filter (28b, 31), welches derart angeordnet ist, daß der zweite und der dritte Strahl (Lp, Lp'/Lp*) in Intensität und/oder Farbe einander gleich werden.

2. Gerät gemäß Anspruch 1, wobei der Polarisationsstrahlenteiler (26) dazu angepaßt ist, den ersten Strahl (Ls) durch Reflexion des S-polarisierten Bestandteils des Strahls (Ls + Lp) der Strahlungsquelle (1) zu erzeugen, und den zweiten Strahl (Lp) durch Durchlassen des P-polarisierten Bestandteils des Strahls (Ls + Lp) der Strahlungsquelle (1) zu erzeugen.

3. Gerät gemäß Anspruch 1 oder 2, wobei der erste Spiegel (28) oder der zweite Spiegel (30a) mit dem optischen Filter (28b) versehen ist.

4. Gerät gemäß einem der vorhergehenden Ansprüche, wobei das optische Filter (31) zwischen dem Polarisationsstrahlenteiler (26) und der Anordnung,

welche die 1/4-Wellenlängen-Platte (27) und den ersten Spiegel (28) aufweist, vorgesehen ist.

5. Gerät gemäß einem der vorhergehenden Ansprüche, wobei das optische Filter (28b, 31) einen mehrlagigen Aufbau hat.

6. Bildanzeigevorrichtung mit einer Strahlungsquelle (1), einem Generator (75) zur Erzeugung eines Bilds durch Modulation eines polarisierten Strahls (Lp, Lp*, Lp', Lp*) und einer Lenkeinrichtung zum Lenken eines Strahls (Ls + Lp) aus der Strahlungsquelle (1) zu dem Generator (75), wobei die Lenkeinrichtung ein Polarisationsbeleuchtungsgerät (121) gemäß einem der vorhergehenden Ansprüche aufweist.

7. Vorrichtung gemäß Anspruch 6, wobei die Lenkeinrichtung einen Kollimator (4) zur Umwandlung des Strahls (Ls + Lp) aus der Strahlungsquelle (1) in einen im wesentlichen parallelen Strahl hat, welcher in das Polarisationsbeleuchtungsgerät (121) geführt wird.

8. Projektor mit einer Bildanzeigevorrichtung gemäß Anspruch 6 oder 7 und einem optischen Projektionssystem (113), um das mittels des Generators (75) erzeugte Bild auf eine vorbestimmte Ebene zu projizieren.

9. Projektor gemäß Anspruch 8, der ferner einen dichroitischen Kreuzspiegel (112) aufweist, auf welchen der zweite und dritte Strahl (Lp, Lp*) gelenkt werden, wobei der Generator (75) aufweist,

   einen ersten Lichtmodulator (75G) zur Modulation und Reflexion des polarisierten Strahls für einen ersten Farbbestandteil (G) der Strahlen (Lp, Lp*), die entlang einer ersten Richtung durch den dichroitischen Kreuzspiegel (112) durchgelassen werden, und zur Erzeugung eines Strahls, der ein erstes Bild anzeigt,
   einen zweiten Lichtmodulator (75B) zur Modulation und Reflexion des polarisierten Strahls für einen zweiten Farbbestandteil (B) der Strahlen (Lp, Lp*), die mittels des dichroitischen Kreuzspiegels (112) in eine zweite Richtung reflektiert werden, und zur Erzeugung eines Strahls, der ein zweites Bild anzeigt, und
   einen dritten Lichtmodulator (75R) zur Modulation und Reflexion des polarisierten Strahls für einen dritten Farbbestandteil (R) der Strahlen (Lp, Lp*), die mittels des dichroitischen Kreuzspiegels (112) in eine dritte Richtung reflektiert werden, und zur Erzeugung eines Strahls, der ein drittes Bild anzeigt,
   wobei das optische Projektionssystem (113) dazu geeignet ist, die Strahlen, welche das erste, zweite bzw. dritte Bild anzeigen, mittels des dichroitischen Kreuzspiegels (112) und des Polarisationsstrahlenteilers (26) des Polarisationsbeleuchtungsgeräts zu empfangen, und mittels der Strahlen ein Farbbild zu projizieren.

10. Projektor gemäß Anspruch 9, wobei jeder der Lichtmodulatoren (75G, 75B, 75R) aus einer Flüssigkristalltafel aufgebaut ist.

Revendications

1. Dispositif (121) d'illumination polarisée destiné à convertir un faisceau (Ls + Lp) émis par une source (1 ; 100) de rayonnement en un faisceau polarisé (Lp, Lp* ; Lp', Lp*), ledit dispositif comportant un diviseur (26 ; 36) de faisceau à polarisation destiné à diviser ledit faisceau (Ls + Lp) émis par ladite source (1 ; 110) de rayonnement en un premier faisceau (Ls) et un second faisceau (Lp ; Lp') ayant des plans de polarisation mutuellement orthogonaux, un montage d'une lame quart d'onde (27 ; 37) et d'un premier miroir (28 ; 38) destiné à faire tourner le plan de polarisation dudit premier faisceau (Ls) pour générer un troisième faisceau (Lp*) d'un plan de polarisation qui est le même que celui dudit deuxième faisceau (Lp ; Lp'), et un second miroir (30a ; 39a) qui est disposé de façon que lesdits deuxième et troisième faisceaux (Lp ; Lp'/Lp*) soient dirigés dans une même direction prédéterminée, caractérisé par un filtre optique (28b ; 31) qui est disposé de façon que lesdits deuxième et troisième faisceaux (Lp ; Lp'/Lp*) deviennent mutuellement égaux en intensité et/ou en couleur.

2. Dispositif selon la revendication 1, dans lequel ledit diviseur (26) de faisceau à polarisation est conçu pour générer ledit premier faisceau (Ls) en réfléchissant la composante à polarisation S dudit faisceau (Ls + Lp) de ladite source (1) de rayonnement, et pour générer ledit deuxième faisceau (Lp) en transmettant la composante à polarisation P dudit faisceau (Ls + Lp) de ladite source (1) de rayonnement.

3. Dispositif selon la revendication 1 ou 2, dans lequel ledit premier miroir (28) ou ledit second miroir (30a) est pourvu dudit filtre optique (28b).

4. Dispositif selon l'une des revendications précédentes, dans lequel ledit filtre optique (31) est prévu entre ledit diviseur (26) de faisceau à polarisation et ledit montage comprenant ladite lame quart d'onde (27) et ledit premier miroir (28).

5. Dispositif selon l'une des revendications précédentes, dans lequel ledit filtre optique (28b ; 31) possè-

de une structure multicouche.

6. Appareil d'affichage d'images comportant une source (1) de rayonnement, un générateur (75) destiné à générer une image en modulant un faisceau polarisé (Lp, Lp* ; Lp', Lp*), et des moyens de direction destinés à diriger un faisceau (Ls + Lp) depuis ladite source (1) de rayonnement vers ledit générateur (75), lesdits moyens de direction comportant ledit dispositif (121) d'illumination polarisée selon l'une des revendications précédentes.

7. Appareil selon la revendication 6, dans lequel lesdits moyens de direction comportent un collimateur (4) destiné à convertir ledit faisceau (Ls + Lp) provenant de ladite source (1) de rayonnement en un faisceau sensiblement parallèle qui est introduit dans ledit dispositif (121) d'illumination polarisée.

8. Projecteur comportant un appareil d'affichage d'images selon la revendication 6 ou 7, et un système optique (113) de projection destiné à projeter l'image générée par ledit générateur (75) sur un plan prédéterminé.

9. Projecteur selon la revendication 8, comportant en outre un miroir dichroïque croisé (112) sur lequel lesdits deuxième et troisième faisceaux (Lp, Lp*) sont dirigés, ledit générateur (75) ayant

   un premier modulateur (75G) de lumière destiné à moduler et réfléchir le faisceau polarisé pour une première composante de couleur (G) desdits faisceaux (Lp, Lp*) transmise à travers ledit miroir dichroïque croisé (112) suivant une première direction, et à générer un faisceau représentatif d'une première image,
   un deuxième modulateur (75B) de lumière destiné à moduler et réfléchir le faisceau polarisé pour une deuxième composante de couleur (B) desdits faisceaux (Lp, Lp*) réfléchie dans une deuxième direction par ledit miroir dichroïque croisé (112), et à générer un faisceau représentatif d'une deuxième image, et
   un troisième modulateur (75R) de lumière destiné à moduler et réfléchir le faisceau polarisé pour une troisième composante de couleur (R) desdits faisceaux (Lp, Lp*) réfléchie dans une troisième direction par ledit miroir dichroïque croisé (112), et à générer un faisceau représentatif d'une troisième image,
   dans lequel ledit système optique (113) de projection est capable de recevoir lesdits faisceaux représentatifs desdites première, deuxième et troisième images, respectivement, à travers ledit miroir dichroïque croisé (112) et ledit diviseur (26) de faisceau à polarisation dudit dispositif d'illumination polarisée, et de projeter une image en couleur à l'aide desdits faisceaux.

10. Projecteur selon la revendication 9, dans lequel chacun desdits modulateurs (75G, 75B, 75R) de lumière est composé d'un panneau à cristaux liquides.

FIG. 1

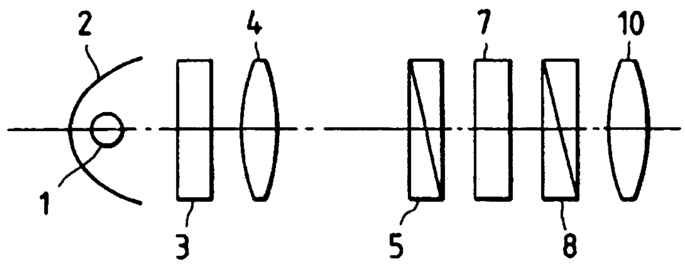


FIG. 2

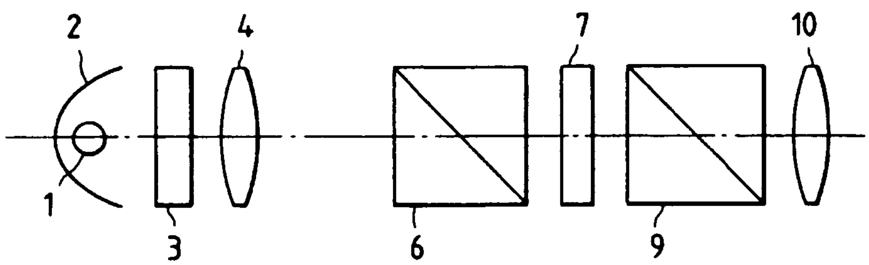


FIG. 3

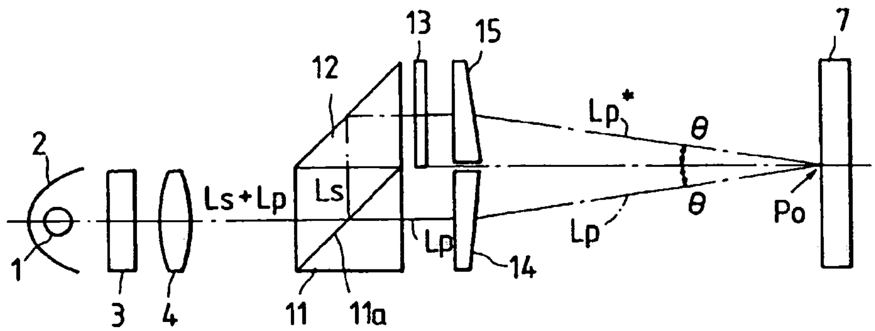

13
15
7
12
Lp*
θ
2
Ls
Ls+Lp
θ
Po
Lp
Lp
1
14
3
4
11
11a

FIG. 4

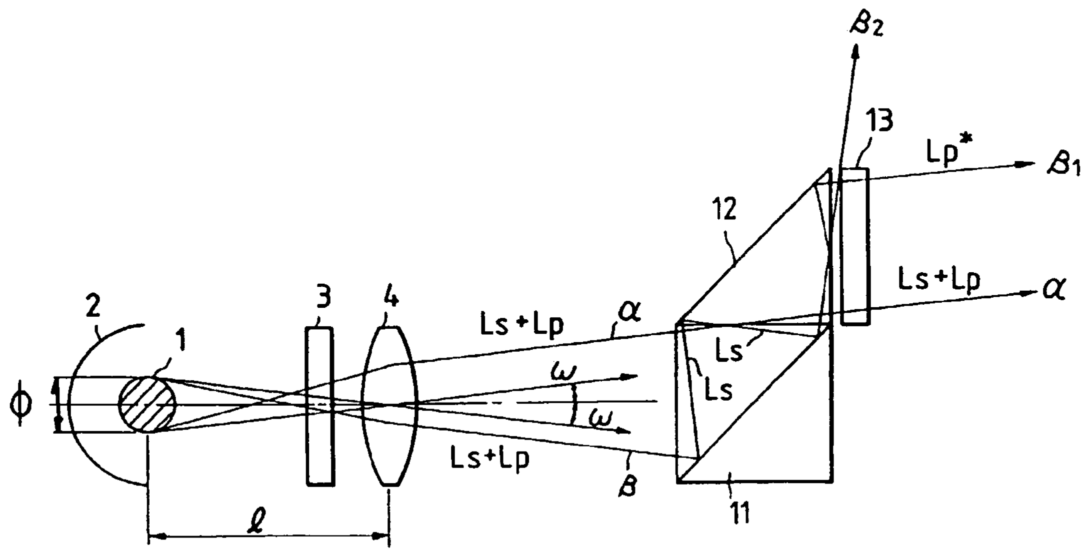

β2
13
Lp*
β1
12
Ls+Lp
α
2
3
4
Ls+Lp
α
1
Ls
Ls
ω
φ
ω
Ls+Lp
β
11
ℓ

FIG. 5

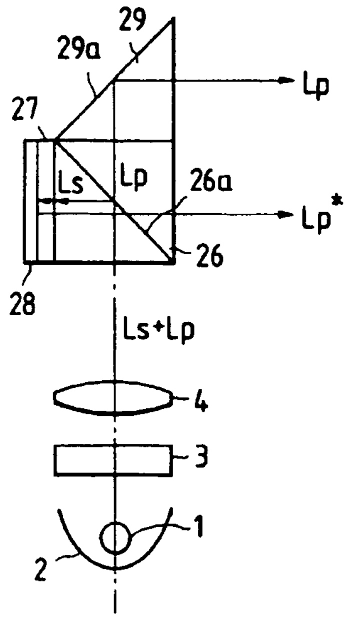

29
29a
27
Lp
Ls
Lp
26a
Lp*
26
28
Ls+Lp
4
3
1
2

FIG. 6

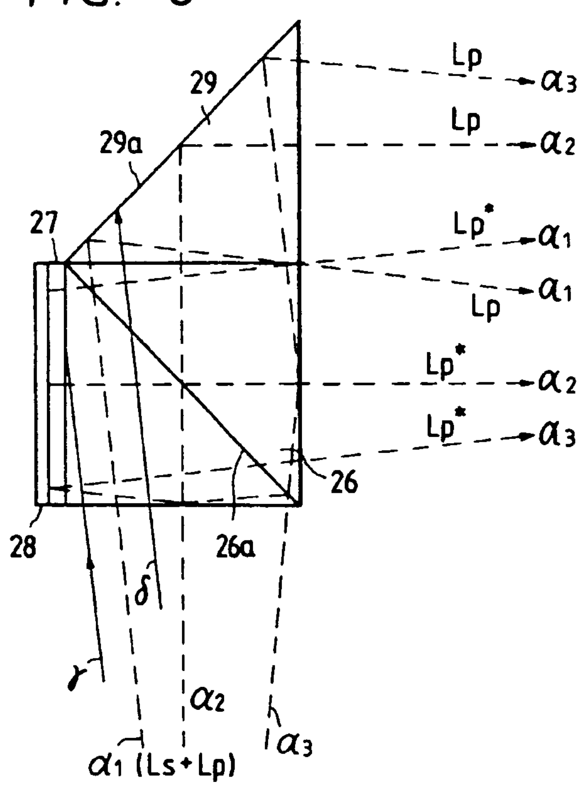

Lp
α_3
29
Lp
α_2
29a
27
Lp*
α_1
α_1
Lp
Lp*
α_2
Lp*
α_3
26
28
26a
δ
γ
α_2
α_3
α_1 (Ls+Lp)

FIG. 7

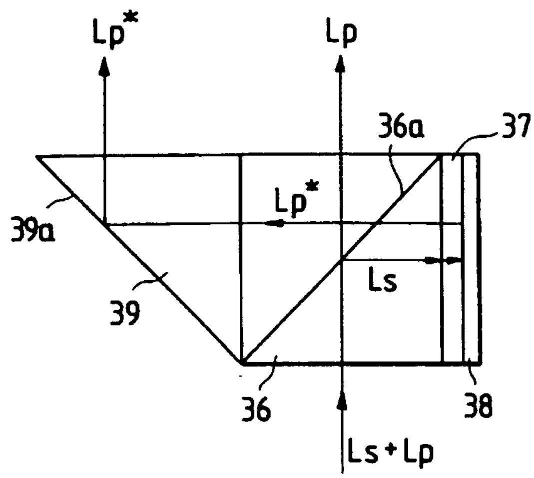

Lp*
Lp
36a
37
Lp*
39a
Ls
39
36
38
Ls+Lp

FIG. 8

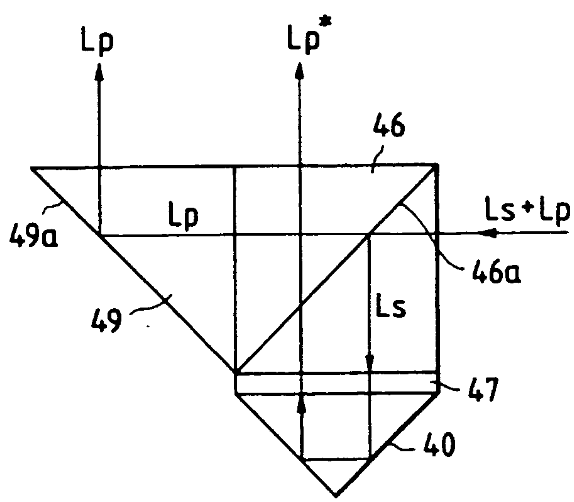

Lp
Lp*
46
Lp
Ls+Lp
49a
46a
Ls
49
47
40

FIG. 9

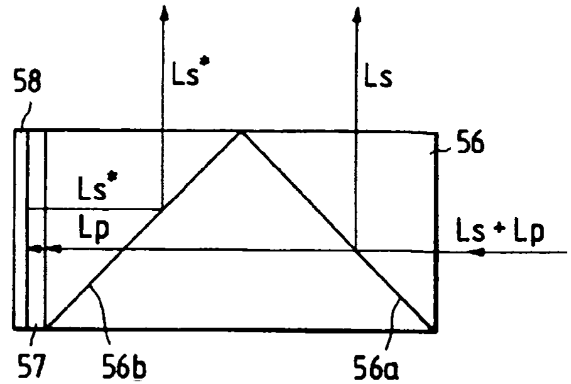

58
Ls*
Ls
56
Ls*
Lp
Ls + Lp
57
56b
56a

FIG. 10

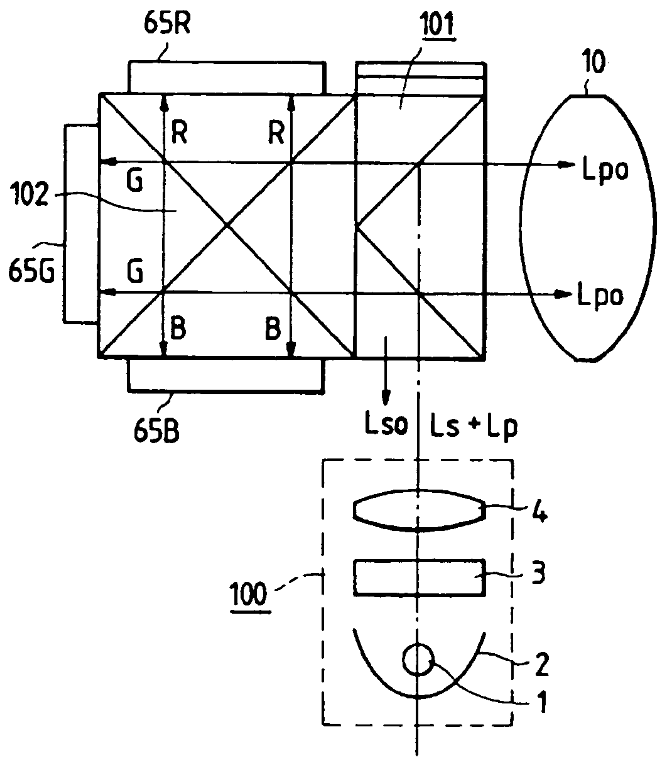

65R
101
10
R
R
G
Lpo
102
65G
G
Lpo
B
B
65B
Lso
Ls + Lp
4
3
100
2
1

FIG. 11A

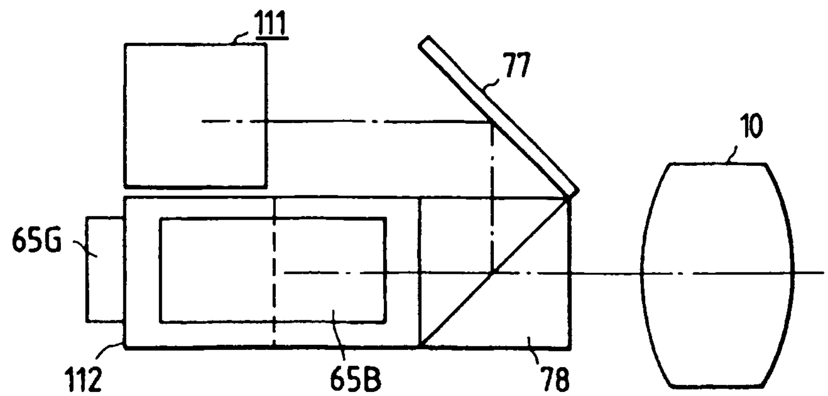


FIG. 11B

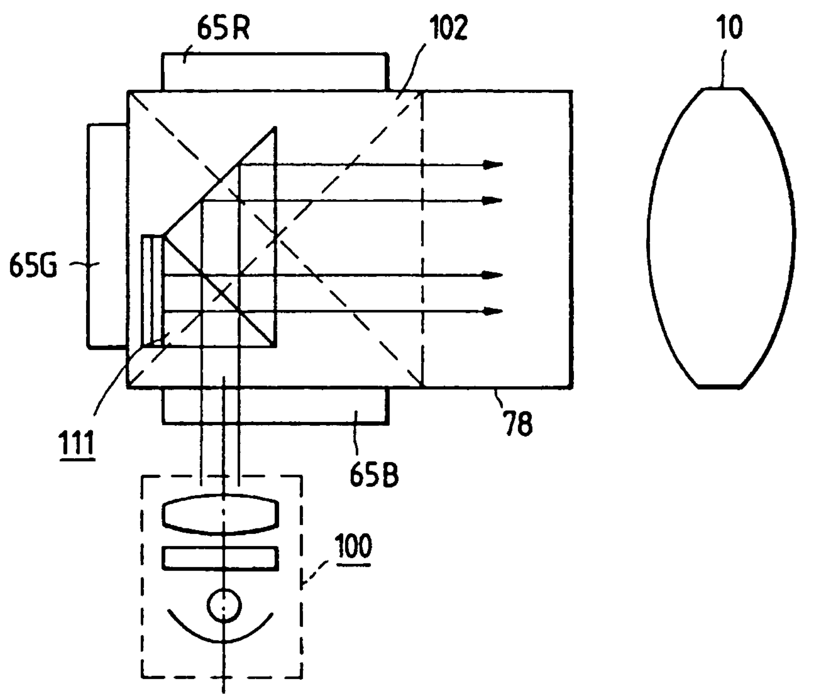


FIG. 12

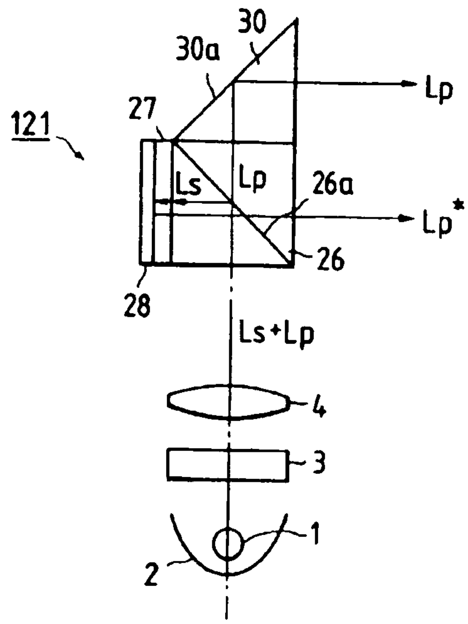

30
30a
27
121
Lp
Ls
Lp
26a
Lp*
26
28
Ls+Lp
4
3
1
2

FIG. 13

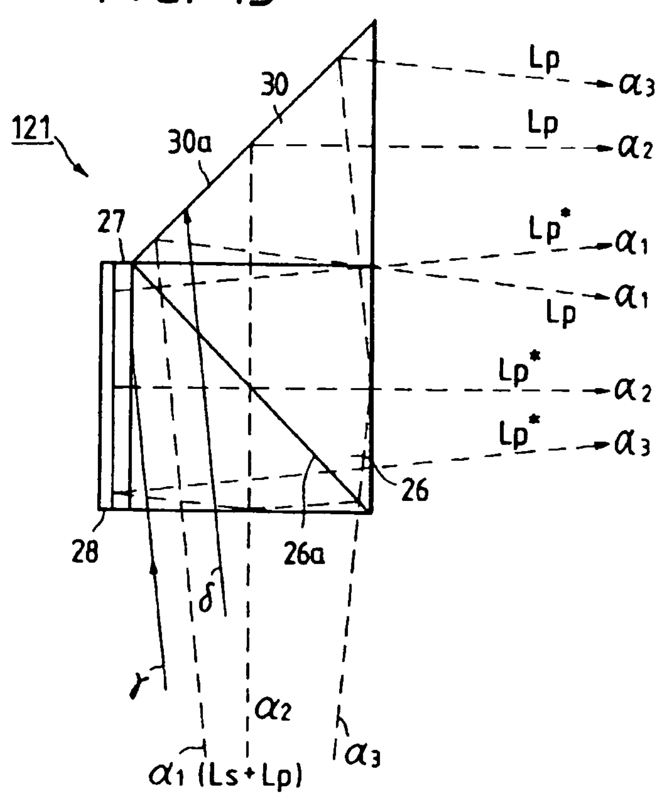

Lp
α3
30
Lp
121
30a
α2
27
Lp*
α1
α1
Lp
Lp*
α2
Lp*
α3
26
28
26a
δ
γ
α2
α1 (Ls+Lp)
α3

FIG. 14

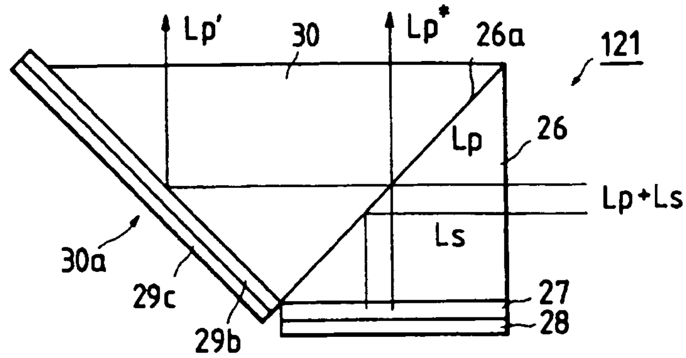


FIG. 15

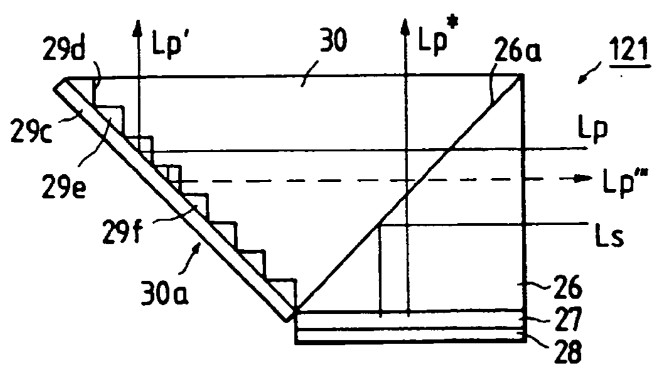


FIG. 16

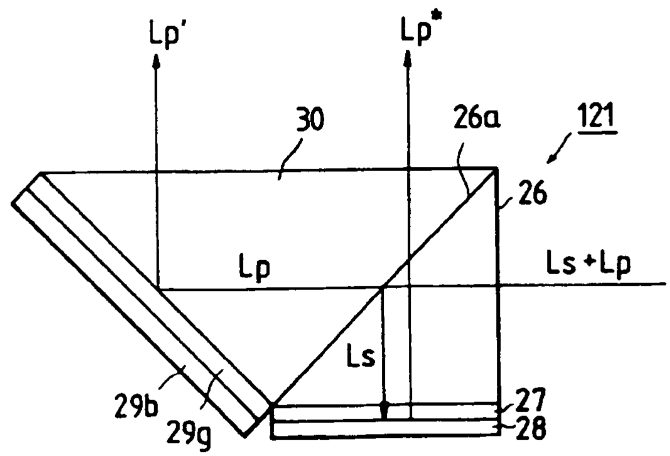


FIG. 17

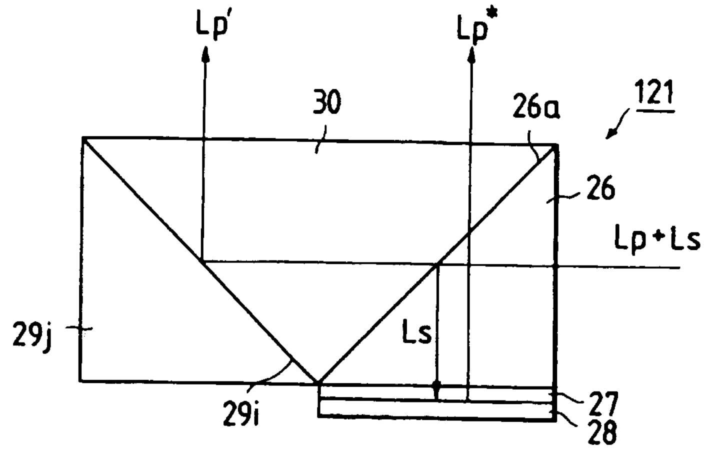

Lp'
Lp*
30
26a
121
26
Lp+Ls
29j
Ls
29i
27
28

FIG. 18

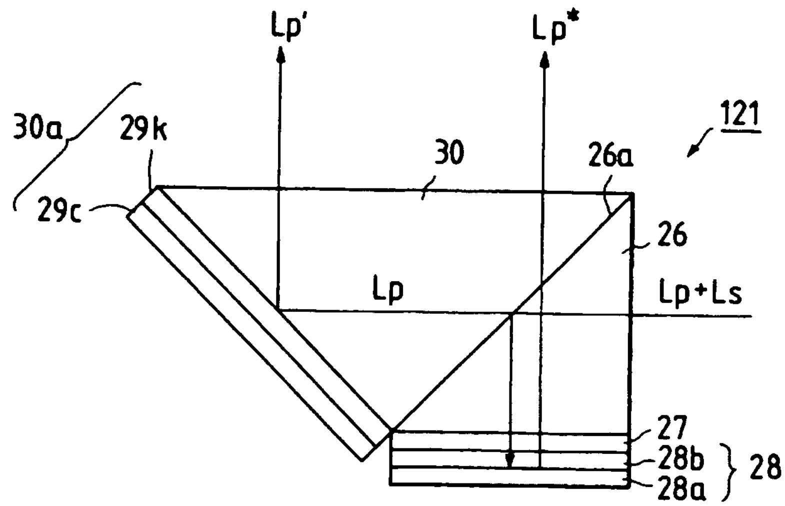
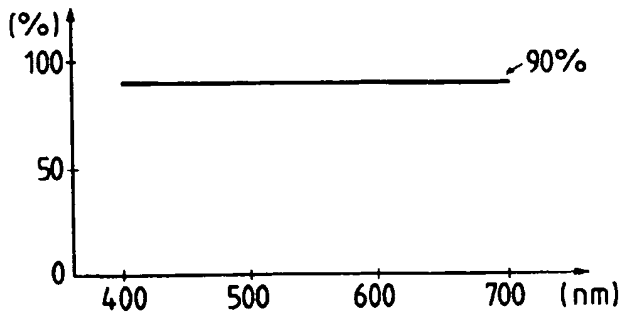
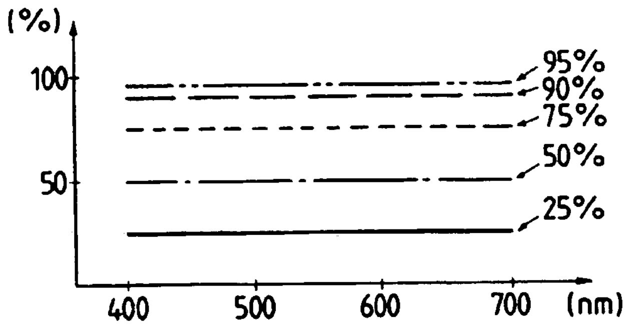

Lp'
Lp*
30a
29k
30
26a
121
29c
26
Lp
Lp+Ls
27
28b
28a
28

FIG. 19A



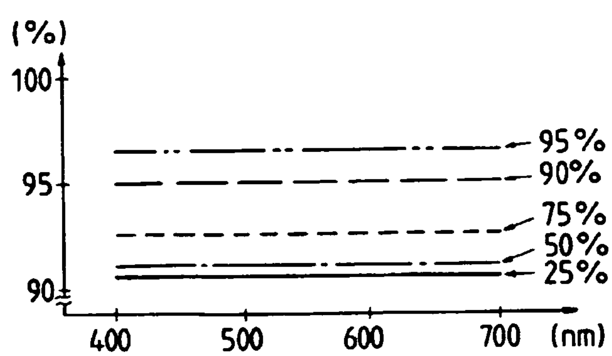
REFLECTIVITY OF ALUMINUM

FIG. 19B



REFLECTIVITY OF OPTICAL MULTI-LAYER FILM

FIG. 19C



TOTAL REFLECTIVITY

FIG. 20

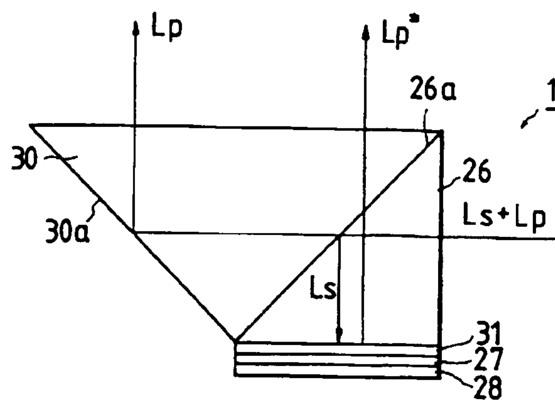


FIG. 21

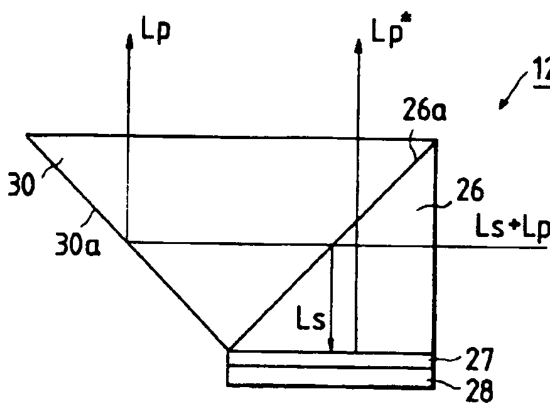


FIG. 22

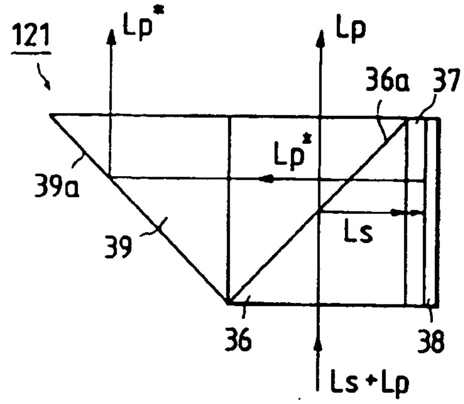


FIG. 23A

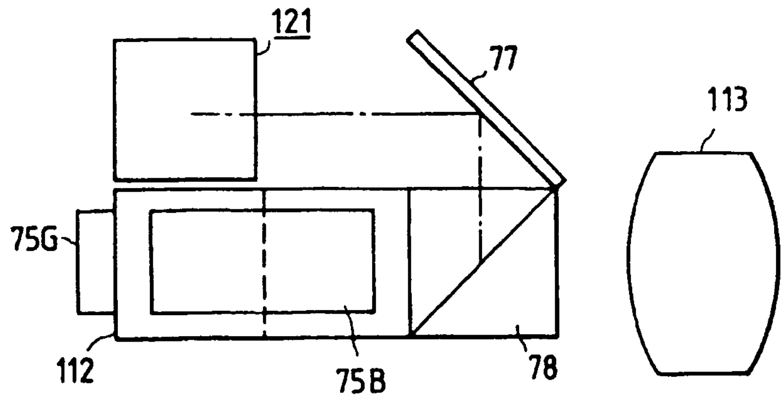


FIG. 23B